DANISH METEOROLOGICAL INSTITUTE

TECHNICAL REPORT

94-22

Correction, Reduction and Homogenization of Barometer Records

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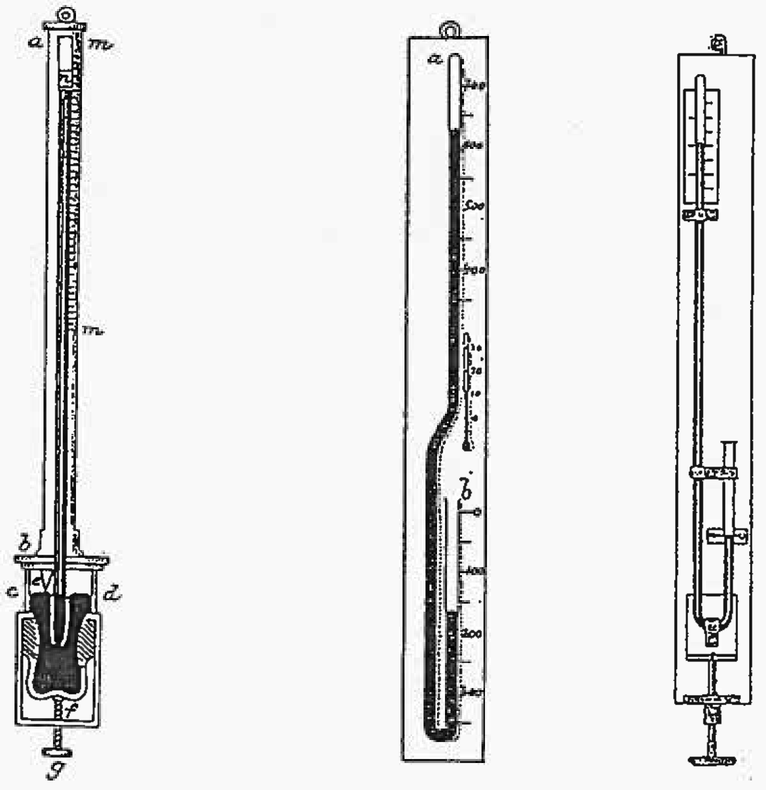

DMI

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1. Introduction.

In order to calculate geostrophic wind and to study temporal variability it is necessary to get homogeneous series of mean sea level (MSL) pressure from different sites, from which we can calculate geostrophic wind by the triangular methods.

Starting at the raw barometer reading we calculate the MSL pressure and here one distinguishes between corrections and reductions. A **correction** is applied to the barometer reading to get the true station pressure, i.e. the correction has to do with the construction and calibration of the barometer. Once having got the station pressure it is possible to get an estimate of the pressure at MSL by applying a height **reduction**. The procedure for correction and reduction outlined below follows WMO - No.8.

Due to changes at the station such as damage, repair or relocation of the instrument inhomogeneities may occur in the time series. Likewise the presence of obstacles to the atmospheric flow such as mountains or buildings may cause a dynamic pressure effect, which should be possibly eliminated. This last step in the process is called **adjustment**.

2. The concept of meta-data.

The aim of meta-data is to create an image of data-emerging at any time and place. This means a file of all aspects that might influence the observations. Type and replacement of instruments, adjusting, repair or cleaning, relocation as well as the observers training, care and precision and the ability of calculating and adjusting the raw-data by the staff of The Meteorological Institute are all part of the meta-data sphere.

So the meta-data conception covers solid elements that can be described precisely (type of instruments, replacements etc.) as well as rather spiritual elements (mental abilities of human beings).

No one should doubt that description of the "solid" elements can be difficult, due to lack of detailed sources and documentation, but treating the various mental abilities might be even more complicated.

3. Information sources.

The observer was equipped with instruments as well as a notebook for entering the readings at 8, 14 and 21 o'clock each day. For the purpose of weather forecast and storm warnings the readings were corrected by the observer and at once telegraphed to Copenhagen as well as customers in Norway, England etc. These observations were included in the daily weather maps , which form the basis of several gridded pressure datasets.

The WASA-dataset, however, comes from lists delivered monthly by the observer, transformed by the staff at the Meteorological Institute and published in the Meteorological Yearbook. The monthly delivered lists contain the readings copied from the observers notebook (without any correction), so all sort of revision, correction and calculation of mean values before publishing were on the responsibility of the staff of DMI.

The monthly lists are filed in the archives of DMI, but normally the observers notebook (prime source) is lost. So are other prime sources like covering letters from observers and correspondence between observers and DMI-staff.

The series of journals (instrument registers, journals of correspondence and parcels/mail items) are not intact, and records known to contain essential information have been lost.

Some "instructions for observers" (rough drafts as well as copies) have been left over, but most of them are undated, and the collections are not complete. Still the remains contain useful information.

Very few inspection reports have survived. Of course all habits of every day observing and data processing practice have never been described neither 100 years ago nor nowadays.

This leaves the investigator of meta-data with an immense jig-saw puzzle. Every piece of information, even what might seem to be unimportant by a first glance, has to fit somewhere. As far as the whole image is not quite sharp, nothing is useless. The meta-data image is linked up from scattered pieces, but no chain is stronger than the weakest link. Collecting meta-data takes time, lots of fruitless searching and lots of thrilling detection. The best method is perseverance.

4. Types of instruments.

4.1 The mercury barometer.

The observers were supplied with a mercury barometer for pressure readings. Besides, some observers had an aneroid barometer or a barograph. The mercury barometer was compared with a normal barometer, sometimes even tested in a metal pressure box. The deviation was noted and a table for temperature corrections was made.

In the 1870'ies the most common type in Denmark, the Faroe Islands, Iceland and Greenland was the adjustable cistern barometer, but in the late 19th and through the 20th century a compensated scale barometer, often mentioned as "Adie for Land Stations" or just "English barometer", perhaps more or less constructed like the Kew type barometer, became more widespread. Types like siphon barometer and marine barometer are mentioned in the files, but mostly for special purpose or short time replacement.

Figure 1 shows the principles sketch of the cistern and siphon mercury barometer types as they were exposed in textbooks of meteorology from the late 19th century. H. Mohn, the Norwegian Meteorological Institute, wrote a textbook (published 1872) which was translated to several languages (German, Russian, Italian, Spanish, French, Polish and Finnish) and this book was rendered to the Danish main station observers. The book may give us an idea of the observers level of knowledge concerning the aim of measurements and the most common instructions of daily instrument handling.

"Travel barometers", a concept used in 19th century inspection reports, are probably Fortin or Kappler cistern barometers. These are most suitable for travelling, as the leather bag can be pressed up until both tube and cistern are filled with mercury to prevent from intrusion of air during transport.

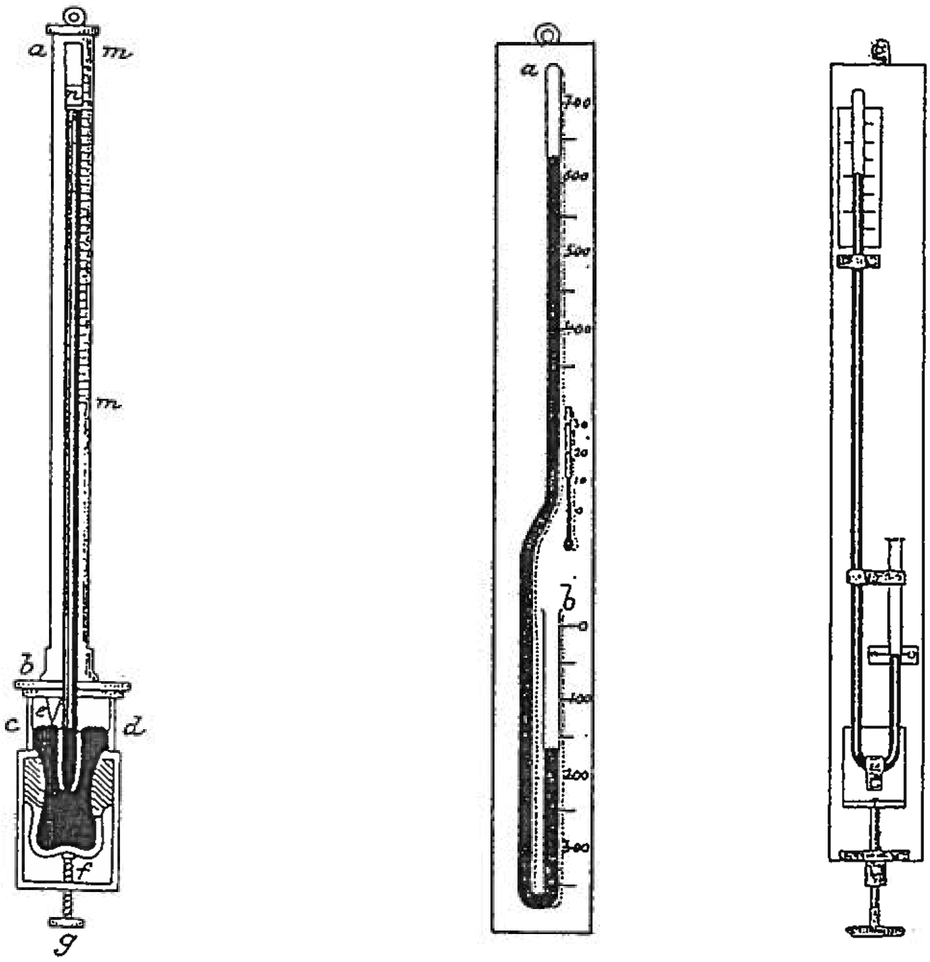

Figure 1. Adjustable cistern barometer and siphon barometer. Source: H. Mohn: Meteorologi, Kristiania 1903 p. 46 & 48; A. Paulsen: Meteorologi og Geografi, Kbh. 1886 p. 25.

Occasionally the "travel barometer" was used for estimating height of a station above sea level. A letter, dated 1880 from the assistant director of the Danish Meteorological Institute V. Willaume Jantzen, refers to an inspection visit in Vestervig at a station located on a school 25 m above sea level. Jantzen and the observer, a local teacher, read the pressure 3 times using the travel barometer in a tripod cardanic suspension, before walking down to the sea (an inlet at Nissum Bredning). 15 Danish inches (about 40 cm) above "daily water level" another 3 readings were done and the height was calculated. The result differed 70 cm from the levelling done by the local surveyor. The assistant director was quite satisfied with this experiment, and later on levelling by a surveyor does not seem to be the common method of height determination.

In the 1920'ies and 30'ies several Danish files mention the station barometer as an "English barometer", some of which are known to be Kew barometers delivered by Negretti-Zambra or Adie in London.

The instrument invented by Mr. P. Adie in 1854, for use at sea, is commonly known as the Kew barometer. The marine barometer is characterized by a constriction in the tube in order to damp out pumping (oscillations of the mercury caused by movements of the ship). The extreme length of the scale is marked on the instrument, but instead of laying off the true measurements on it, the inches or millimetres are shortened from the upper part downwards in proportion to the relative sizes of the diameters of the tube and cistern.

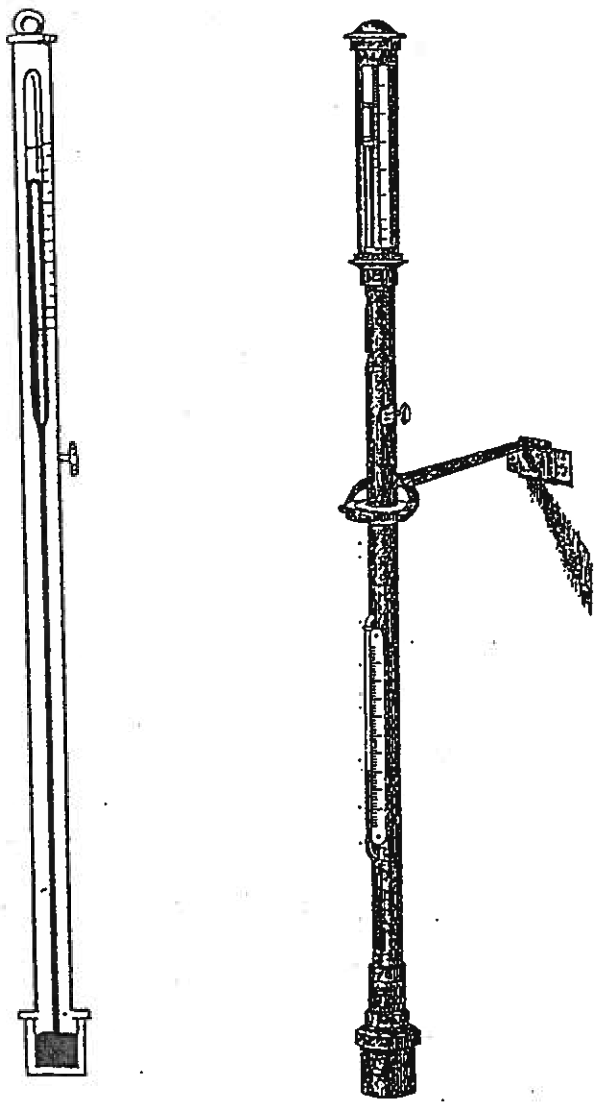

Figure 2. Marine barometer, Kew pattern. Source: H. Mohn: Meteorologi, Kristiania 1903 p. 49 & R.H.Scott: Elementary Meteorology, London 1883 p. 74.

As mentioned in an English textbook (R.H.Scott, 1883) the Kew barometer were coming more and more into use every day, and the Danish observers seem to have received Kew type barometers from the late 19th century replacing the Fortin adjustable cistern barometer. Figure 2 shows the marine barometer, Kew pattern.

Figure 3 shows the Lambrecht model of station barometer used in Denmark, the Faroe Islands and Greenland in the 20th century. These pictures, to some extend used for teaching and instructing observers, are picked from a catalogue of instruments, unfortunately undated and anonymous, but certainly dating before 1948.

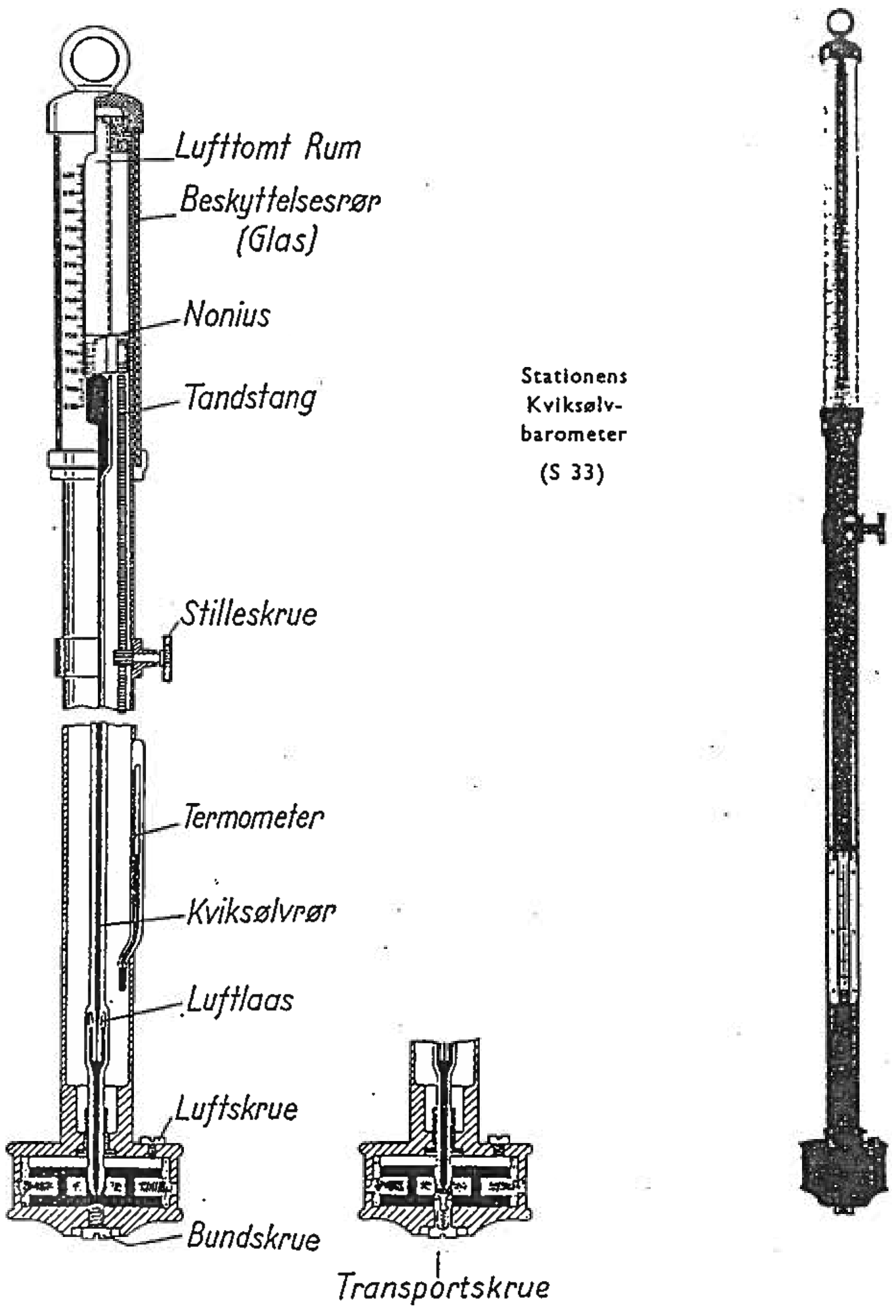

Figure 3. Compensated scale barometer used by observers in the 20th century, replacing the Fortin or Kappler cistern barometer. Source: Undated and anonymous catalogue.

This instrument is a compensated scale barometer, the scale constructed like the scale of the marine barometer. Similar to the marine and Kew type barometer, the mercury tube of the station barometer is constricted and furthermore supplied with an air trap.

The station barometer (cardanic suspension) was inert to movements. An instruction dated 1910 for the station "North Star Bay" says:

"If the barometer is moved from vertical position, you must wait 4-5 minutes must before reading to let the mercury repose."

A vernier scale was used for reading since 1872. A very enthusiastic observer in Nordby, Fanø has described his endeavour teaching a 50 years old housekeeper reading the barometer and using the vernier scale.

5. Corrections.

Three corrections have to be applied namely:

- index error (instrumental error)
- gravity ("latitude correction/correction to 45 °N"), performed on routine basis since 1893. Since 1953 correction is made to standard gravity.
- temperature("correction to 0°C/32°F")

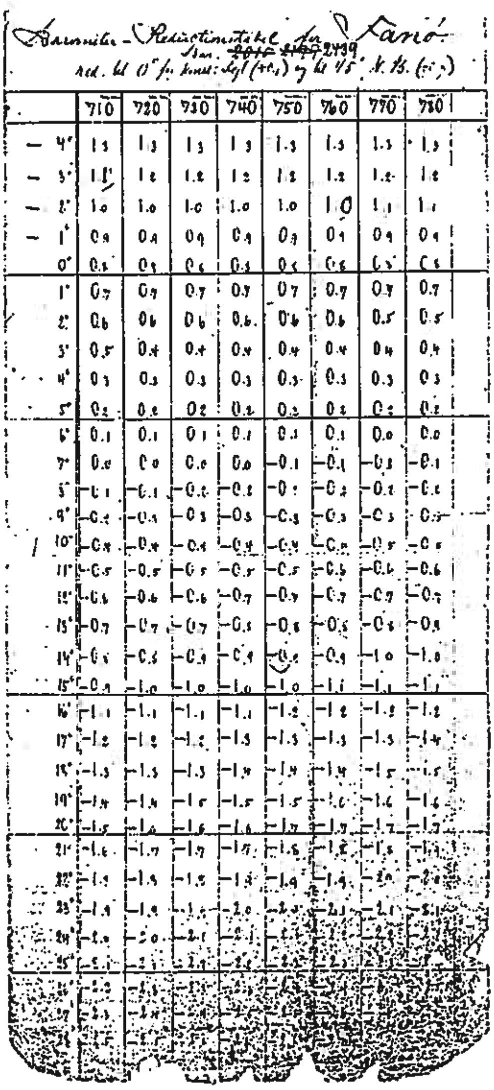

Figure 4. Barometer reduction table for Nordby, Fanø 1887. Barometer no. 2015, 2177, and 2439 were consecutively replacing each other through the period of 1887-1936. Instrumental correction was +0.1 mm and latitude correction +0.7 mm Hg.

A correction table, often generated separately for each barometer, was handed over to the observer for the purpose of telegraphing daily readings. Obviously a similar table was used by the staff at DMI. Figure 4 shows a barometer reduction table for barometer no. 2015, 2177 and 2439 consecutively replacing each other in Nordby, Fanø in the period of 1887-1936.

5.1 Correction for index error.

Before delivered to the observer the barometer was compared with a normal barometer. A metal pressure box was used at the Danish Meteorological Institute in the 1870'ies, the construction described in the 1872 Instrumental Journal. This test might not serve the verification of scale or capillarity error. The testing of various pressure levels simply lead to calculation of the mean deviation from the normal barometer. According to WMO -No 8 the index error should not exceed a few tenth of a hPa. In certain cases, however, it might be larger du to e.g. impurities in the mercury or defective vacuum, according to WMO - No 8 up to 5 hPa.

5.2 Correction for barometer temperature.

The barometer reading B at standard conditions is given by

$$B = \rho_0 g_n l$$

ρ_0 being the density of mercury, $g_n = 9.80665\, m\ s^{-2}$ the standard gravity, and l the level difference in the barometer. If B_t is the barometer reading corrected for temperature and $\alpha = 0.0001818\, K^{-1}$ the volume thermal expansion coefficient for mercury we have

$$\begin{aligned} B_t &= \rho_t g_n l \\ &= \frac{\rho_0}{(1+\alpha t)} g_n l \\ &\approx \rho_0 g_n l(1-\alpha t) \\ &= B + C_t \end{aligned}$$

where the correction for temperature is given by

$$C_t = -\alpha B t$$

A more accurate treatment of the problem gives the formula

$$C_t = -0.000163(B - 47hPa)t$$

for modern Kew-type barometers. Putting in realistic values we get $C_t \cong 3hPa$. According to WMO - No 8 the uncertainty in the correction is below 0.1 hPa, which seems reasonable referring above.

5.3 Correction for gravity.

To get the best estimation of station pressure the local value of gravity g, depending on latitude, height over MSL and local topography, must be used. If g is not known from geophysical measurements WMO - No. 8 gives a formula for calculation.

The barometer reading corrected for temperature and gravity is

$$\begin{aligned} B_{gt} &= \rho_t g l \\ &= B_t \frac{g}{g_n} \\ &= B_t + C_g \end{aligned}$$

where

$$C_g = B_t [\frac{g}{g_n} - 1]$$

Putting $g = 9.82 m s^{-2}$ we get an estimation of the magnitude of the correction as $C_g \cong 1 hPa$.

6. Reduction to mean sea level.

Having determined the station pressure $p_s = B_{gt}$, it is desirable to reduce the pressure to MSL. Combining the law for hydrostatic pressure

$$\frac{dp}{dz} = -\rho g$$

and the equation of state

$$\frac{p}{\rho} = RT$$

yields

$$\frac{dp}{p} = -\frac{g\,dz}{RT}$$

which can be integrated to the hypsometric equation

$$\ln \frac{p_s}{p_0} = -\frac{g}{R} \int_0^h \frac{dz}{T} \quad ,$$

h being the station height. This equation is the foundation of all the different reduction formulae. The problem is, that the air column between the station level and MSL is fictitious, and therefore a reasonably temperature distribution must be assumed.

In Denmark, where no station has an altitude above app. 100 m, the hypsometric equation integrates to the simpler formula

$$\ln\frac{p_s}{p_0} \approx \frac{p_s - p_0}{p_0} = -\frac{g}{R}\frac{h}{T_s}$$

is used, giving the reduction to be added

$$R_h = p_0\frac{g}{R}\frac{h}{T_s} \approx p_s\frac{g}{R}\frac{h}{T_s} \cong 10hPa$$

for $h \cong 100m$.

There are several problems to be discussed concerning the procedure mentioned above. It is essential that T_s is representative for the air mass, i.e. that we have no local temperature gradient near the ground. This might be the reason why WMO - No 8 suggests using annual normal temperature instead of observed temperature. In situations with strong winds it can generally be assumed, that local variations does not exist, and in that case it is better to use observed temperature. However there might be stations in very mountainous areas with 'local silence' even in situations with strong gradient. Such stations can be determined from wind statistics, and in these cases it might be better to use normal temperature.

Secondly to increase the accuracy, one should use virtual temperature in order to incorporate the humidity of the air. Usually the difference between temperature and virtual temperature is below 5 K.

Lets try to evaluate the significance of the uncertainty in the temperature, i.e. we estimate the uncertainty in the reduction as

$$\delta R_h \cong p_s\frac{g}{R}[\frac{\delta h}{T_s} + \frac{h\delta T_s}{T_s^2}] \cong 1hPa + 0.5hPa$$

where we have put $\delta T_s = 10K$, and $\delta h = 10m$. We thus conclude that it is important to know the height of the barometer as well as the air temperature with greater accuracy than 10 m respectively 10 K.

7. Adjustments.

7.1 Inhomogeneities.

As mentioned in the introduction it may occur that certain events at the station may cause inhomogeneities in the pressure record. Reasons for that could be erroneous observation instrument, undocumented movement of the barometer etc.

Detection of such inhomogeneities is in general not an easy task. Sometimes the inhomogeneity takes the form of an abrupt change of level, a so-called 'break', and in that case it is possible to detect the break by a statistical method, the Standard Normal Homogeneity Test, described in Steffensen et al. (1993). Typically around five breaks is detected in a 100 year barometer record, the magnitude being of the order of 1hPa.

The principle of this method is to compare the station under investigation with other stations in the neighbourhood which are considered homogeneous. In practice we cannot be sure that any station is homogeneous and we must use the method in a self-consistent way as follows: The test-stations is tested against, say five reference stations. If a break is detected at the same year (approximately) using all possible subsets of the five reference stations, then it is very likely that a break is present. If a barometer replacement is known from the station history to have occurred, this fact further supports the presence of a break.

In practice the homogeneity test is carried out on monthly data du to the very time consuming calculations.

The detection of breaks is a matter of statistics and one must choose a level of significance. As a thumb rule one choose 10% significance level for a break if it is supported in the meta data. Sometimes a break is detected without any support in the meta data, in which case we choose a 5% significance level.

Finally it should be mentioned, that the method is able to detect inhomogeneities in form of gradual changes - 'trends'. However in that case care must be taken for the reason that such inhomogeneities are hard to differ from climatic trends. I general it is not advisable to define such inhomogeneities for pressure. series

7.2 The effect of dynamic pressure.

As we are interested in the MSL pressure of the undisturbed atmosphere we should reduce for the effect of the pressure distribution around obstacles to the atmospheric flow. It is necessary to distinguish between small scale obstructions such as buildings and large scale obstructions such as mountains.

In the first case it should be expected, that turbulence might tend to average out the difference between static and dynamic pressure over the time of observation. This hypothesis is confirmed by measurements carried out on DMI in windy situations.

In the latter case the large scale obstructions (orography) sets up a stationary pattern which require adjustments. We can get an idea of the order of magnitude of the effect by using Bernoulli's equation

$$p_0 + \tfrac{1}{2}\rho v^2 = p_0 + \Delta p$$

from which we get at $v = 25m/s$

$$\Delta p = \tfrac{1}{2}\rho v^2 \cong 4hPa$$

That is how far we can get in the first place. To proceed further one must analyse weather maps or compare neighbouring stations with different wind-climate. This has not been done for any Danish stations on a routine basis, but is done on the Icelandic station Vestmannaeyjar. It might be necessary to do similar adjustments within the WASA-project, a question which still remains to be investigated.

8. Conclusion.

Let us try to sum up in a scheme the different contributions in correcting, reducing and adjusting a time series of raw barometer readings:

	Max. magnitude (hPa)	Uncertainty (hPa)
Correction for index error.	0.1	0.1
Correction for temperature	3	0.1
Correction for gravity	1	0.1
Reduction, 100 m - MSL	10	1
Adjustment, inhomogeneity	5	1
Adjustment, dynamic pressure, 25 m/s	4	?

From this we see immediately, that the most serious error source might show up to be the dynamic pressure effects, at least for some stations. Only later investigation can show how serious the problem is. Apart from dynamic pressure effects the MSL pressure is theoretically determined within app. 1 hPa.

Acknowledgements

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